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# Systems Engineering and Test: An Improved Partnership Enabled by Modeling and Simulation

Fred A. Myers

Systems Engineering Directorate, Office of the  
Secretary of Defense (OSD), Washington, D.C.

James W. Hollenbach

Simulation Strategies, Incorporated

*With the Department of Defense's (DoD's) new emphasis on capability-based acquisition, modeling and simulation (M&S) will necessarily assume a more important role in the acquisition process. However, there are obstacles to effective use and reuse of trustworthy models and simulations. This paper describes the initiative led by the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, Defense Systems, to identify needed actions to improve the use of M&S. The needed actions will be the building blocks for a forthcoming Acquisition M&S Master Plan. This paper highlights those actions with the most significant implications for systems engineering and test.*

After more than a decade of acquisition reform, with diminished government involvement in systems engineering, there has been a realization that a disciplined systems engineering approach must be re-emphasized as a critical component of effective systems acquisition. The Acting Under Secretary of Defense for Acquisition, Technology and Logistics issued a policy memorandum in February 2004 that directed a revitalization of systems engineering (SE) in the development and testing process. He further directed the establishment of a senior-level Department of Defense (DoD) Systems Engineering Forum to oversee its implementation. This was the first of a series of acquisition policies and guidance to address planning and management for SE revitalization. The SE Forum includes participation by the military departments and defense agencies to leverage their activities and provide a collaborative means to foster SE discipline across DoD.

## Modeling and simulation imperative

As the DoD components have sought to reduce the cost, time and risks associated with systems acquisition, there has been a persistent and pervasive interest in applying modeling and simulation (M&S) to help throughout the acquisition process, from capability trades, to design, manufacturing, test, operations and sustainment. DoD's 2003 commitment to acquire functional capabilities, not just individual systems, has greatly increased the number of variables and interactions that must be considered in any acquisition. The resulting complexity, adverse pressure on schedules and

risk, as well as practical limitations on DoD's ability to test functional capabilities in a realistic environment have all contributed to an intense interest in how M&S can help. As a byproduct of this interest, the department also recognized that M&S use in acquisition is far from optimal, with many obstacles precluding its efficient and effective use.

## Acquisition M&S Working Group

These factors led the SE Forum to establish an Acquisition M&S Working Group (AMSWG) to consider the matter of M&S support to acquisition and to make recommendations to the forum. The AMSWG membership mirrors that of the SE Forum and is composed of people with some mix of expertise in both acquisition and M&S. The author, a GS-15 official from the OUSD (AT&L) DS/SE organization, chairs the AMSWG. AMSWG members individually report to their component's SE Forum principal, thus helping ensure the AMSWG focuses on M&S support to the systems acquisition process, and not simply on M&S as an end in itself. The AMSWG also has enlisted the help of other organizations not otherwise represented on the SE Forum, such as the Defense Modeling and Simulation Office (DMSO) and Defense Intelligence Agency.

The SE Forum chartered the AMSWG to produce four deliverables:

- (1) Definition of M&S processes for better SE in acquisition;
- (2) Identification of gaps in enabling M&S processes;

- (3) Actions to address the gaps; and
- (4) An Acquisition M&S Master Plan (AMSMP)

To enable it to produce these deliverables from a broadly informed perspective, the AMSWG established working relationships with both industry and the DoD M&S community, as depicted in *Figure 1*.

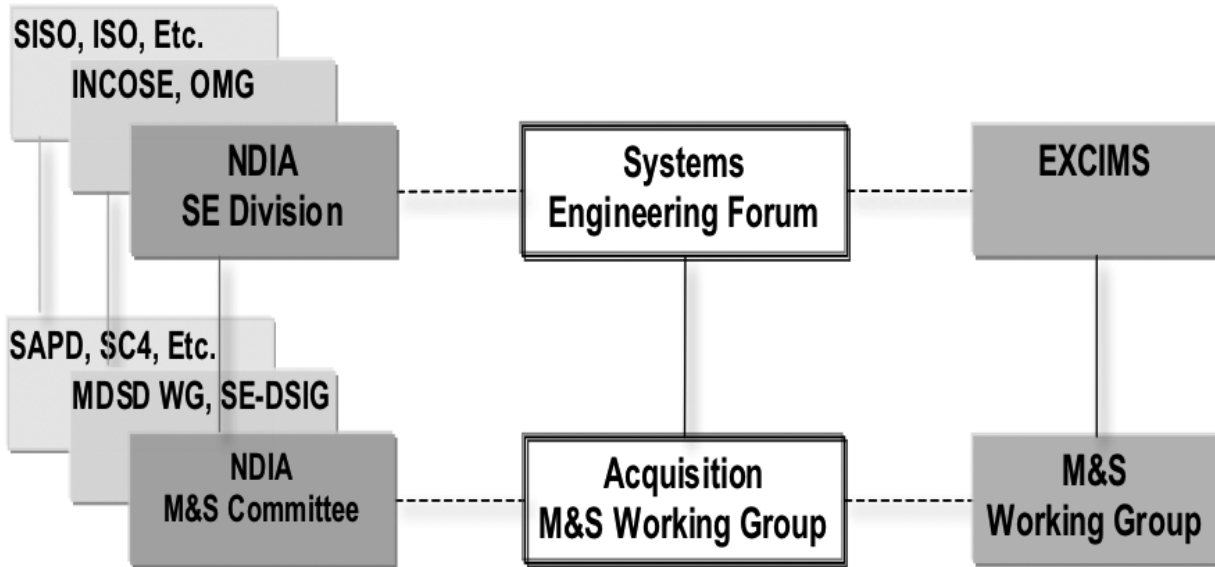


Figure 1. Acquisition Modeling and Simulation Working Group (AMSWG) relationships

The substantive relationships among the organizations depicted in Figure 1 are extensive. For example, the chair of the SE Forum is a member of the DoD Executive Council for Modeling and Simulation (EXCIMS), the department's senior management body for M&S, and is also the chairman of the National Defense Industrial Association (NDIA) Systems Engineering Division's Government Steering Group. The chair of the AMSWG is a member of both the M&S Working Group and the NDIA M&S Committee. At his request, the NDIA M&S Committee in February 2004 submitted a report on "M&S Support to the New DoD Acquisition Process."

The chair of the M&S Committee is a participant in the work of the other industry bodies shown in Figure 1 and consults with the AMSWG. Thus, there have been strong lines of communication among the organizations, providing great value to the AMSWG. The AMSWG has leveraged the findings and recommendations of the NDIA M&S committee report. Further, the NDIA M&S Committee has hosted presentations by government and industry programs that are "getting their hands dirty" at the intersection of SE and M&S. The AMSWG participates in and draws information from such discussions.

### AMSMP development process

The AMSWG began its task by agreeing to some foundational philosophies to guide its work. The AMSWG agreed it should focus on M&S issues and actions necessary to enable acquisition of effective joint capabilities (systems-of-systems [SoS]) and would not

seek to do the job of program/capability managers, but rather, seek to empower them by:

- Removing systemic obstacles in their path;
- Identifying new options for approaching their tasks; and
- Helping to realize broadly needed M&S capabilities beyond the reach of individual programs.

To develop an AMSMP, the AMSWG conducted two complementary analyses. The first was a careful harvesting of the insights accruing from the past and present work of others. Recognizing that many studies of M&S support to acquisition had been conducted over the past decade by various groups, from Defense Science Boards to industry associations, the AMSWG first harvested, sifted and merged the findings and recommendations of these studies.<sup>1</sup> This was followed by an examination of lessons from those government and industry organizations that were attempting SE on a functional capability/SoS level. The AMSWG and NDIA M&S Committee therefore invited presentations by the three military departments, the Joint Single Integrated Air Picture Systems Engineering Organization, the Missile Defense Agency, the Future Combat Systems program, several field activities and four prime contractors (Lockheed Martin, Raytheon, Boeing and BAE Systems). These affirmed most of the

findings and recommendations from the studies and provided valuable new inputs as well. Together, these steps identified many systemic problems to M&S use and provided a rich set of recommended actions. These are not just focused on the models and simulations themselves, but they also address directly related areas such as management, standards, information sharing, business rules and education.

However, this initial set of actions was not directly traceable to a clear definition of a desired end state, and there was no assurance the list was exhaustive. Therefore, the AMSWG conducted a second, top-down analysis by first identifying the desired end state and systematically analyzing it to understand the implications for M&S. The AMSWG recognized the CJCSI 3170.01E and DoDD 5000.1 as definitive DoD statements of the desired acquisition environment. Treating the cited characteristics of the desired acquisition environment as customer requirements, the AMSWG used an SE requirements analysis approach to derive the SE capabilities (including test) needed to satisfy those requirements:

- Early, continuing SE from an SoS/family-of-systems (FoS) capabilities perspective; seamless transition from JCIDS to acquisition.

- Lifecycle-wide exploration of the maximum available trade space, including time-phased requirements and technology insertion.

- Collaboration among all stakeholders (multiple government and contractor organizations) for key enterprise-level SE decisions.

- Rapid assessment of concept/design alternatives.

- Comprehensive, accurate, event-based assessment of technical baselines; avoidance of costly fixes for problems discovered late in the cycle.

- Focused, effective and efficient testing; including testing conducted at the capability level.

- Appropriate reuse of all resources—information, software tools, expertise, facilities, ranges and so forth—across programs and organizations.

Continuing with that top-down requirements analysis process, the group then defined the M&S processes needed to enable those SE capabilities. The AMSWG then compared the gaps it had identified via the harvesting process against those processes. Finding disconnects (for example, the processes causing examination of areas where gaps had been overlooked, and the gaps prompting a revision of the process descriptions), the AMSWG iteratively defined a comprehensive list of gaps and the actions needed to close them.

## Coordination with others

The acquisition community's effort to develop an AMSMP is just one of several efforts to improve the use of M&S within DoD. DMSO developed a DoD-wide M&S Master Plan. Both the training and analysis com-

munities are developing their own M&S master plans for their respective functional areas. Each of the functional plans will relate to the objectives set forth in DMSO's M&S Master plan.

A few of the other related activities include: Service projects such as the Joint Service Battlespace Environment; information management efforts under the Assistant Secretary of Defense for Networks and Information Integration (ASD[NII]); the initiatives of other federal government activities such as the National Institute of Standards and Technology and the National Aeronautics and Space Administration; and the various M&S-related projects underway in industry, both defense and commercial. As of fall 2005, the AMSWG had embarked on a series of liaisons with such organizations to leverage and support the activities they had underway to meet needs each had in common. Thus, the AMSWG hopes to informally align the vectors of these various activities. Once the AMSWG better understands how its efforts can best complement those of others, it will finish drafting its master plan and present it to the SE Forum for its consideration. This will be followed by formal coordination and promulgation.

## Actions relevant to SE/test and evaluation activities

Because the list of actions to be included in the AMSMP will likely continue to be refined during the coordination process described previously, it would be premature to attempt to provide an exhaustive list on those actions in this paper. However, it is already clear that many of the actions may have a significant impact on DoD's SE/test and evaluation (T&E) activities. The following brief discussion of key actions is offered. These are organized under the five objectives expected to be included in the AMSMP: (1) Provide necessary policy and guidance; (2) enhance the technical framework for M&S; (3) improve M&S capabilities; (4) improve M&S use; and (5) shape the workforce.

### **Objective 1: Provide necessary policy and guidance**

The AMSMP is expected to call for a DoD policy to require documented M&S planning at the functional capability and program levels as part of the SE Plan, T&E Strategy and T&E Master Plan. The AMSMP-proposed action is meant to: (1) Require the documentation of M&S planning; (2) include it as part of key SE and testing documents, rather than in a stand-alone M&S support plan; and (3) require M&S be explicitly addressed at the functional capability level, not just at the individual program level.

The AMSMP will recommend the establishment of more explicit DoD policy on the appropriate use of M&S to plan tests, to complement live tests and to eval-

uate functional capabilities. Going back at least as far as 1997, when then-Director, Operational Test and Evaluation, Dr. Philip Coyle, and then-Director of Developmental Test, Systems Engineering and Evaluation, Dr. Patricia Sanders, published the Simulation, Test and Evaluation Process (STEP) guidelines, there has been general agreement that M&S has a complementary role to play vis-à-vis live testing. However, the implementation of this concept has proven contentious due to the lack of definitive guidelines regarding the appropriate role, extent and fidelity of the models and simulations. Although public law has been clear regarding the testing of individual systems under realistic conditions, DoD's intent to orient its acquisition activities on functional capabilities calls into question the extent to which evaluation of those capabilities need to be accomplished in live testing versus M&S. The AMSMP action is intended to clarify such issues.

Another key action in the AMSMP will be to promote model-based SE (MBSE) and M&S-enabled collaborative environments at both the program and functional capability levels. Implicit in this action is the inescapable conclusion that SE, including integration and testing, is required at both the capability and individual system levels.

Figure 2 represents this concept.

MBSE is an emergent concept under the International Council on Systems Engineering (INCOSE) and the Object Management Group (OMG). MBSE calls for the use of automated SE tools, which are modeling environments, to analyze requirements, develop architectures and specify constraints.

The individual perspectives (views) are integrated into, and generated from, an underlying database. Embedded simulation is used to verify the architecture and assess its merits (completeness, rough measures of performance). Reports and other documents are generated automatically off the

underlying database. There is a growing suite of commercial tools that provide such capabilities, exemplified by 3SL's Cradle, Vitech's Core and Telelogic's Tau.

M&S-enabled collaborative engineering environments provide a means to share authoritative information across an acquisition enterprise and use interoperable modeling environments, models, simulations and distributed environments to communicate, design, assess, immerse warfighters, integrate, verify and test.

All of these MBSE and collaborative environment capabilities assist in designing a system, but the AMSWG regards them as particularly useful in conducting SE at the capability level. The development of an integrated architecture at that level, specifying the interfaces and the interactions among the systems that make up a SoS, will be an immensely useful framework for the development of those individual systems. Beyond that, it will provide a very valuable, even essential, specification for the testing of both individual systems and the SoS.

The AMSWG identified a need for a DoD policy to require DoD-wide standardized documentation of M&S verification, validation and accreditation (VV&A). The inability to clearly understand what VV&A has been

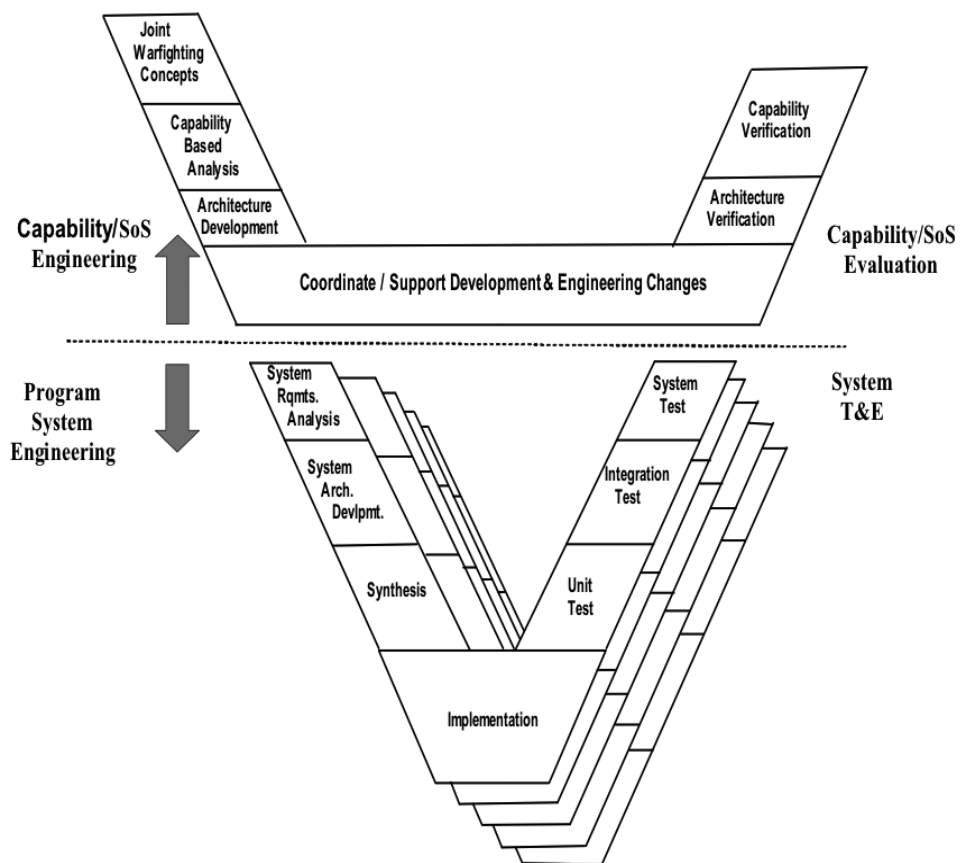


Figure 2. Systems-of-systems engineering "V" diagram

accomplished has degraded the usefulness of much M&S. This will be a step toward correcting that.

### **Objective 2: Enhance the technical framework for M&S**

With respect to an improved technical framework, the AMSMP will call for developing a product development information metamodel and associated metadata extensions to the DoD Discovery Metadata Specification. The use of trustworthy (authoritative) information is a prerequisite to trustworthy M&S. If sufficient metadata (data about data) does not accompany a data item, it may be misunderstood and misused. For example, proper use of a parameter such as an aircraft's combat radius, or a data set such as its radar cross-section, require an understanding of its applicability (what type/model/series of the aircraft) and the operational assumptions that went into its calculation (flight profile, aspect angle and so forth). Having a standard template and glossary for capturing such metadata will help alleviate this sort of confusion, make VV&A easier and otherwise aid M&S trustworthiness.

Another proposed action for the master plan is a task to establish a forum to clarify the characteristics and application of various distributed simulation standards (HLA, TENA, DIS and so forth), as well as the examination of opportunities for convergence. The AMSWG heard ample testimony that numerous distributed simulation standards were having adverse cost and schedule impacts on DoD's efforts to readily assemble distributed environments, as envisioned under concepts such as the Joint Distributed Engineering Plan and Testing in a Joint Environment Roadmap.

### **Objective 3: Improve M&S capabilities**

The AMSWG recognized a needed action to establish a risk-based methodology and associated guidelines for verification and validation (V&V) expenditures. If V&V is done during model or simulation development, it is a cost-effective way to develop a trustworthy M&S tool that satisfies its specified requirements. Likewise, if the pedigree of an input data set is well documented (see previous metadata discussion), its use in V&V is greatly facilitated. Unfortunately, V&V for many of the legacy M&S tools and data sets has either not been documented well or has not been performed at all. Having to perform V&V by reverse-engineering a model, tool or associated input data set can be a very expensive undertaking. Weighing such expenditures by an agreed-upon risk-based methodology will be prudent stewardship of the taxpayers' money and will facilitate reaching consensus on whether the use of a model and simulation to support SE or T&E is appropriate.

The AMSMP will include an action for fostering readily available distributed live-virtual-constructive environments by first leveraging related initiatives to arrive at a unified approach. It will call for DoD-wide standards for distributed environments but leave to the DoD components the tasks of making candidate simulations, laboratories and ranges compliant with these standards and providing services to help plan and conduct distributed events. (The business model for these environments—who pays how much for what—are addressed separately under the AMSMP Objective 4.)

Centrally developing and maintaining high-priority, broadly needed M&S tools is another action to be proposed in the master plan. The analysis showed there currently is no good way to develop and maintain widely needed M&S tools that cut across programs. Most funding comes from the next customer; there are rarely funds to insert one-off modifications made to a model or simulation back into "street version," update the tool based on empirical evidence (for example, test results)<sup>2</sup> or build in needed new capabilities soon enough that they are available for that next customer. The AMSMP will likely call for a three-step approach to establishing this concept: (1) Identify and prioritize broadly needed M&S tools; (2) conduct one or more pilot projects to develop new tools and/or update existing ones to meet these needs; and (3) expand the scope of central M&S tool management as warranted by pilot project results and the list of common M&S needs.

### **Objective 4: Improve M&S use**

Responsibility for defining best practices for disciplined M&S planning and employment will be proposed in the AMSMP. This should include rigorous analysis of M&S requirements and alternative solutions, followed by selection of the best course. This practice should also address configuration management, initialization, execution and post-run analysis; and it should include cautions against inappropriate use and approaches to maximize cost-effective and reuse across the lifecycle. Such a best practice should aid both program offices and test authorities in the determination of what M&S use is appropriate.

The AMSMP will include an action to establish a DoD-wide business model for compensating providers of reusable M&S resources (for example, information, tools and services). This is the key to resolving a broad range of M&S use issues, including the realization of the distributed environments/virtual ranges seen as essential to T&E.

As a complementary action to the promotion of MBSE discussed earlier, the plan also will call for assessing the use of commercial off-the-shelf SE tools (modeling environments) for collaborative architecture development.

The definition of integrated architectures will provide an essential framework for the SE and T&E of both individual systems and functional capabilities provided by a SoS.

The master plan will specify the need for acquisition oversight organizations to examine the VV&A of any M&S used to inform major acquisition decisions. It will likewise call for a requirement for program officials to unambiguously state the purpose, key assumptions and significant limitations of each model or simulation when results are presented. Such actions should help improve the overall quality of DoD's M&S efforts and thereby make it easier to credibly employ M&S to support T&E.

### **Objective 5: Shape the workforce**

Because of the importance of having a properly educated acquisition workforce, the AMSMP will call for the definition of required M&S competencies for the acquisition workforce, which of course includes the T&E community. Understanding what is required is the first step in improving the community's M&S expertise so that it can weigh wisely an M&S strategy and options.

To better educate the acquisition workforce regarding M&S, the specific actions were identified to include the collection and enhancement of the M&S body of knowledge, as well as its delivery via an expanded set of Defense Acquisition University courses, Professional Military Education, the Acquisition Guidebook and on-line Continuous Learning Modules, an improved M&S Information Analysis Center, conferences, workshops and assist visits.

### **Conclusion**

The SE Forum has appreciated the benefits of better M&S support to the development and testing of both individual systems and functional capabilities. It has wisely called for the publication of an M&S Master Plan for the acquisition community to guide its collective efforts. This paper has described the methods and means to develop this plan and has briefly surveyed key actions expected to be included. Many of the actions will fall to the OSD acquisition staff to lead, but some will likely be led by other organizations because of their applicability beyond acquisition. If successfully accomplished, the AMSMP actions should be of great value to both the SE and T&E communities. The draft master plan is scheduled for official staffing early in calendar year 2006. Comments and suggestions are invited. □

*FRED A. MYERS is the principal assistant for Developmental Test and Evaluation in the Systems Engineering Directorate of the Office of the Secretary of Defense (OSD). He is responsible for drafting Department of Defense (DoD) acquisition policy and guidance relating to*

*developmental testing. He is the program support team leader for OSD systems engineering and test oversight of automated information systems. His other responsibilities include advancing an OSD initiative to improve the use of modeling and simulation in acquisition and leading OUSD (Acquisition, Technology and Logistics) efforts to update the test and evaluation curriculum for the acquisition workforce. He received his master's degree in engineering administration from George Washington University and is an engineering graduate of Geneva College. Email: fred.myers@osd.mil.*

*JAMES W. HOLLENBACH is the president of Simulation Strategies, Incorporated, and is an independent consultant to government and industry in modeling and simulation (M&S), systems engineering and enterprise integration. He chairs the M&S Committee of the National Defense Industrial Association System Engineering Division. He previously served in the U.S. Navy, as a naval aviator and DoD acquisition professional. His last active duty assignment was as director of the Defense Modeling and Simulation Office.*

### **Endnotes**

<sup>1</sup> The 16 studies were: (1) Final Report of the Acquisition Task Force on M&S, OUSD(AT&L)/DDRE, 1994; (2) Naval Research Advisory Committee Report on M&S, 1994; (3) Collaborative Virtual Prototyping Assessment for Common Support Aircraft, Naval Air Systems Command, 1995; (4) Collaborative Virtual Prototyping Sector Study, North American Technology & Industrial Base Organization; 1996; (5) Application of M&S to Acquisition of Major Weapon Systems, American Defense Preparedness Association, 1996; (6) Effectiveness of M&S in Weapon System Acquisition, OUSD(AT&L)/DTSE&E, 1996; (7) Technology for USN and USMC, Vol. 9: M&S, Naval Studies Board, National Research Council, 1997; (8) A Road Map for Simulation Based Acquisition, Acquisition Council of EXCIMS, 1998; (9) M&S for Analyzing Advanced Combat Concepts, Defense Science Board Task Force, 1999; (10) Advanced Engineering Environments, National Research Council, 1999; (11) Survey of M&S in Acquisition, DOT&E/LFT&E, 1999 and 2002; (12) Test and Evaluation, Defense Science Board Task Force, 1999; (13) SIMTECH 2007 Workshop Report, Military Operations Research Society, 2000 (14) M&S in Manufacturing and Defense Systems Acquisition, National Research Council, 2002; (15) M&S Support to the New DoD Acquisition Process, NDIA Systems Engineering Div. M&S Committee, 2004; and (16) Missile Defense Phase III M&S, Defense Science Board Task Force, 2004.

<sup>2</sup> On October 3 1995, the USD(A&T), Dr. Paul Kaminski, stated, "Our underlying approach will be to model first, simulate, then test, and then iterate the test results back into the model." This guidance has only rarely been followed since.